Saskatchewan
Agriculture
and Food

ADF

AGRICULTURE DEVELOPMENT FUND

FINAL REPORT

20040479

ODOUR EMISSION CONCENTRATION AND INTENSITY AFTER SURFACE AND SUB-SURFACE APPLICATION OF MANURE IN SASKATCHEWAN

Funded by: The Agriculture Development Fund

October 2007

Prepared by: University of Saskatchewan

University of Saskatchewan
College of Engineering

Odour emission concentration and intensity after surface and sub-surface application of manure in Saskatchewan

Saskatchewan Department of Agriculture, Food and Rural Revitalization (SAFRR)
Agriculture Development Fund (ADF) Program
Project #: 20040479
MIDAS #: 000373

Final report submitted to:
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1. SUMMARY

The general objective of the project was to develop a preliminary assessment of the emission reduction potential of liquid manure injection and to provide scientific values on the odour intensity surrounding a manure application site. The main purpose of the project was to yield valuable and previously unavailable data on odour emission concentrations and intensity after surface application and injection of liquid manure in the Saskatchewan climate and topography. Additionally, the established protocols and baseline data will allow the emission reduction potential of future technologies to be evaluated. The results will also help intensive livestock regulators establish set-back distances for manure application that minimizes odour nuisance to neighbours and increases the area of land available for spreading, allowing for environmentally sustainable growth of the livestock industry.

As a result, the specific objectives of the research were:

- To evaluate existing protocols of surface emission determination following land application of manures and, if required, to develop new protocols for sample collection;
- To evaluate the odour emission reduction potential of liquid injection based on surface emission data, and
- To evaluate the odour intensity and dispersion after manure application based on the nasal ranger data.

Surface emissions measurements were measured using a dynamic flux chamber and dynamic dilution olfactometry. Plot-scale applications were used to minimize costs and to better control variables such as type of manure, application method and application rate. Simulated hand application was also used in some cases due to logistical challenges of measurement and analysis of odours.

Based on these plot studies and the surface odour concentration data, odour emissions from the injection plots were up to 64% lower than emissions from broadcast applications (57% for liquid dairy simulated application, 45% for liquid dairy with PAMI injectors, 64% for solid swine simulated application, 26% for liquid swine with the PAMI injectors, and 15% for solid feedlot manure simulated application). In one case (simulated application of the liquid swine manure), the odour emissions from the injected plots were 65% higher than emissions from the surface plots. Odour emissions from solid manure were 50% lower than from liquid manure. In general, odour emissions from liquid and solid manure increased with higher application rates but not significantly above the control rate until the application rate reached two to three times the normal annual application rate. For the plots applied with the PAMI injector, the odour emissions from the swine manure were higher than the emissions from the dairy manure, but this difference was not significant in the simulated application plots. In addition, greenhouse gas emission data suggest that injection of both liquid and solid manure does not significantly increase the total emissions of carbon dioxide equivalents.

The odour intensity data collected during this study is somewhat contradictory and less reliable than the surface odour emission data. In general, the odour intensities downwind of the liquid broadcast sites were lower than the odour intensities downwind of the liquid injection sites. However, varying application rates and the size of the area the manure was applied to may have influenced these conclusions.

Generally, solid applications produced higher intensities than liquid applications, but the spikes in odour from the solid applications were very intermittent with several readings of zero intensity following each intensity spike. Although no high intensity odours were observed beyond 600 m downwind, it is possible that solid broadcasting can produce high intensity odours up to 1 km downwind in neutral or stable atmospheric conditions. Based on the surface emission results, injection of manure does reduce the odour emissions, but the odour intensity data collected in this study does not reflect that conclusion.

2. INTRODUCTION

2.1 Project background and rationale

Land application of animal manure is an efficient and effective way of recycling important by-products from livestock production. Manure nutrients benefit soil crop-systems by building up and maintaining soil fertility. In addition, manure can also improve soil tilth, increase its water-holding capacity, lessen wind and water erosion, improve aeration, and promote the establishment and growth of beneficial organisms. There are two principle objectives in applying animal manure to land: 1) ensuring maximum utilization of the manure nutrients by crops and 2) minimizing negative environmental impacts. In order to achieve these goals, land application equipment must precisely and accurately distribute the material while dynamically controlling application rates to meet soil and crop requirements based on the nutrient content of the manure. Emissions to the atmosphere and runoff potential may be reduced by injection or incorporation of the manure into the soil surface.

Almost half of all complaints about an intensive livestock facility are due to odours following land application of manure. In addition, odours are the main concern in communities where the development of a new livestock facility is proposed. In order to allow for the sustainable growth of the livestock industry, the odour emissions from livestock facilities must be reduced to improve the public perception of intensive livestock operations. A range of gaseous emission mitigation strategies have been developed across the different manure management stages, and land spreading is the source where the most cost-effective strategies can be employed. These mitigation strategies consist of alternative slurry application techniques and rapid incorporation of manures into the soil after application. However, scientific values of the odour reduction potential of manure injection into agricultural soils are limited since very little research has been dedicated to odour measurement after injection of liquid manure. Additionally, the set-back distances between land applied sites and neighbours in Saskatchewan are not based on scientific data since odour dispersion and intensity data after land application does not exist for the Saskatchewan climate. Improved set-back distances based on scientific data will increase the area of land available for land application while reducing the odour nuisance to neighbours, allowing for environmentally sustainable growth of the livestock industry.

The increased environmental scrutiny regarding the water pollution potential of manure application has brought into question the accuracy of the application of traditional manure spreaders. In addition, the adoption of the Kyoto Protocol will eventually make it economically beneficial to producers to reduce greenhouse gas emissions from their operation, which may be an added benefit to liquid manure injection. Finally, reducing the odours and improving the visual aesthetics associated with land application of manure will increase the public acceptance of the practice.

2.2 Review of literature

Most researchers agree that the land application of manure is one of the three major sources of odour production resulting from swine production, but the majority of research to date has focussed on the emissions from manure storage facilities and production buildings. Various studies have already shown that for slurry the best way of reducing ammonia volatilization is to reduce the air contact of the slurry by incorporation or injection. However, the effects of the mode of application (broadcast or sub-surface injection) of liquid manure on the odour emissions from soil surfaces have not been extensively studied.

The methods and protocols for surface emission measurement (odours per square meter) are well established in previous research and are outlined in the detailed review of literature in the Appendix in Section 8.1. Information from previous work includes results of odour emissions from various modes of application of liquid manure to grasslands, the use of Nasal Rangers (or trained odour assessors) for odour

intensity measurement and the use of flux (or dynamic) chambers versus wind tunnels for odour emission research.

2.3 Objectives

The general objective of the project was to develop a preliminary assessment of the emission reduction potential of liquid manure injection and to provide scientific values on the odour intensity surrounding a manure application site; the specific objectives of the research were:

- To evaluate existing protocols of surface emission determination following land application of manures and, if required, to develop new protocols for sample collection;
- To evaluate the odour emission reduction potential of liquid injection based on surface emission data, and
- To evaluate the odour intensity and dispersion after manure application based on the nasal ranger data.

This final report was prepared to satisfy the reporting requirements outlined in Appendix B of Agreement (Project #: 20040479; MIDAS #: 000373) between the Saskatchewan Department of Agriculture, Food and Rural Revitalization (SAFRR) and the University of Saskatchewan (UofS) within the scope of the Agriculture Development Fund (ADF) program. It includes the following sections: 1. Summary; 2. Introduction; 3. Methods; 4. Results; 5. Conclusions and recommendations; 6. Acknowledgements; 7. Literature cited; 8. Appendices; 9. Administrative and other aspects.

3. METHODS

3.1 Evaluation of existing protocols and development of new ones

3.1.1 Existing methods and protocols

The assessment of existing methods and protocols for the determination of surface emissions was completed by means of a comprehensive review of the relevant literature. A detailed review of existing methods and protocols for the determination of surface emissions of gases and odours was completed and the results are presented in Appendix 8.1.

3.1.2 Development of new methods and protocols

3.1.2.1 Dynamic chambers and wind tunnel

Two types of dynamic chambers were designed and evaluated based on repeatability and gas flux recovery rate: a circular dynamic chamber and a rectangular dynamic chamber (0.28 m^2 and 0.323 m^2 surface area respectively). Descriptions and pictures of the chambers can be found in Appendix 8.2. The operating flow rates were varied between 0.24 and 1.89 L/s (0.5 and 4 cfm). A wind tunnel was also evaluated at the same time as the two dynamic chambers.

3.1.2.2 Chamber evaluation and calibration

A calibration box was designed and built to help evaluate and calibrate the dynamic chambers to be used for flux measurements. The soil topped box was filled with CO_2 to simulate a known CO_2 flux through the soil surface. The chambers were placed on the soil surface and operated at various sweep air flow rates to determine the optimum operating conditions. A complete description and diagram of the

calibration box along with the protocols for the evaluation and calibration tests can be found in Appendix 8.2.

3.2 Evaluation of odour emission from surface emission data

3.2.1 Preliminary Plot Testing

Preliminary plot tests were conducted to establish baseline odour emission values and to finalize the sampling protocols to be used to collect odour and GHG samples. Small plots (1 m x 1 m) were outlined on a bare soil and liquid swine manure (6.7% total solids, 3.35 kg ammonia as N per m^3 manure, 5.62 kg total N per m^3 manure) was applied at 56 m^3/ha using simulated splash plate application. Some of the plots were also "incorporated" immediately after application using a garden hoe. The rectangular dynamic chamber was deployed within 10 minutes of application. The sweep air (0.944 L/s) was allowed to wash through the chamber for at least 10 minutes before the sample was drawn to ensure the odour flux had reached steady state. The sample was drawn using a vacuum box into a 10 L Tedlar bag and sent to the U of A olfactometry lab for measurement of odour concentration within 24 hours of sampling. The odour emission rate was calculated using Equation 3.2.1:

$$E = OU * \frac{Q}{A} \qquad (3.2.1)$$

Where E = odour emission rate (OU/m^2-s)
OU = odour concentration measured by olfactometry (OU/m^3)
Q = flowrate of the sweep air in the dynamic chamber (m^3/s)
A = area covered by the chamber (m^2)

All mathematical manipulations (calculation of average and standard deviations and determination of statistical significance) of the odour emissions were performed using the logarithmic values of the odour concentrations.

3.2.2 Full Factorial Plot Testing

Odour emissions from surface and subsurface application of liquid and solid manure were measured on a plot scale using the rectangular dynamic chamber and dynamic dilution olfactometry. Plots (rather than full-scale field testing) were used to control variables such as application rate and application method and type of manure. Liquid swine and liquid dairy manure and solid swine and feedlot manure were surface applied and injected at three application rates with 3 repetitions. Odour emission data was collected using the same equipment and protocols as the preliminary plot work.

One set of plots utilized the liquid injection tanker truck at PAMI for surface and injected applications of swine and dairy manure. The plots were 10 m long and 3 m wide with 3 m spacing between plots. Manure was applied along the entire 10-m length and measurements were taken at random spots in the middle of the plot (to ensure the target application rate had been reached). The chambers were deployed within 20 minutes of application. For the injected plots, manure was injected to a depth of 7.5 to 10 cm. The target application rates were chosen to simulate typical one-year and two-year application rates based on the nitrogen content of the manure. Since nitrogen losses due to volatilization are lower for injected manure, the injected application rates were reduced accordingly. Due to limitations of the achievable application rate, additional rates of one half and one quarter of one year rates were also used (surface applied manure at a 2 year rate was not feasible). The liquid manure application rates for the full-factorial plot trial are outlined in Table 3.2.1 and the chemical properties of the manure used in these plots are in Table 3.2.2.

Table 3.2.1 Liquid manure application rates for full-factorial plot trial.

	Dairy (m^3/ha)		Swine (m^3/ha)	
Rate	**Surface**	**Injected**	**Surface**	**Injected**
0.25X	21	8	23	9
0.5X	42	17	47	18
1X	84	34	94	37
2X	n/a	68	n/a	75

Table 3.2.2 Liquid manure chemical properties for PAMI injector truck plots.

	Total Solids (%)	Ammonia as N (kg/m^3)	Total N (kg/m^3)
Swine manure	2.0	2.99	3.46
Dairy manure	7.0	2.03	3.58

Another set of smaller plots (2 m x 1 m) utilized "simulated" manure application of liquid and solid manure. Due to the logistical restrictions of the olfactometer lab, application equipment and land availability, "simulated" manure application proved to be more practical than using actual application equipment. The application rates were calculated based on the area of the plot and the volume and mass of liquid and solid manure, respectively, required to simulate typical application rates. Since samples would be collected within 10 minutes of application (limiting the amount of time available for volatilization) and in order to make the comparisons between surface and injected applications easier, the application rates for surface and injected applications were equivalent. The application rates simulated in these plot trials are outlined in Table 3.2.3 and the chemical properties of the manure used in the "simulated" plots are in Table 3.2.4.

Table 3.2.3. Liquid and solid manure application rates for "simulated" application plots.

Rate	Solid (Mg/ha)	Liquid (m^3/ha)
1X	20.2	56.1
2X	40.4	84.2
3X	60.6	112.2

Table 3.2.4. Manure chemical properties used in "simulated" application plots.

	Total Solids (%)	Ammonia as N (kg/m^3)	Total N
Solid feedlot	38.2	n/a	8.3 kg/Mg
Liquid dairy	6.9	0.60*	2.5 kg/m^3
Solid swine	43.2	n/a	7.0 kg/Mg
Liquid swine	2.8	2.88	3.24 kg/m^3

*Note: Liquid dairy manure was "generated" by taking fresh semi-solid manure directly from alley of barn and diluted with equal parts of water, resulting in little time for microbial activity and generation of NH_4-N.

For liquid surface application, the manure was poured from a bucket over a 10 cm diameter "splash plate" about 30 cm above the surface of the ground and covered the entire plot. For liquid injection, two furrows were cut into each plot 30 cm apart to a depth of 7.5 cm using a garden edging tool (see Figure 3.2.1a). The liquid manure was then poured through a spout in the pail evenly into each furrow (Figure 3.2.1d). For solid surface application, the pre-weighed manure was simply forked over each plot (Figure 3.2.1b). To simulate solid injection, a single furrow was cut into the soil using the edging tool. Because solid injection results in more soil disturbance than liquid injection, the furrows for the solid injection were

wider and the depth varied between 7 and 10 cm (see Figure 3.2.1c). Also, because the injector prototype spacing is 40 cm, the chambers could only accommodate one furrow. The application rates were adjusted to accommodate the effective plot size of the injected plots. Solid manure injection for the 2x application rate is pictured in Figure 3.2.1e (before covering) and 3.2.1f (after covering and with dynamic chamber).

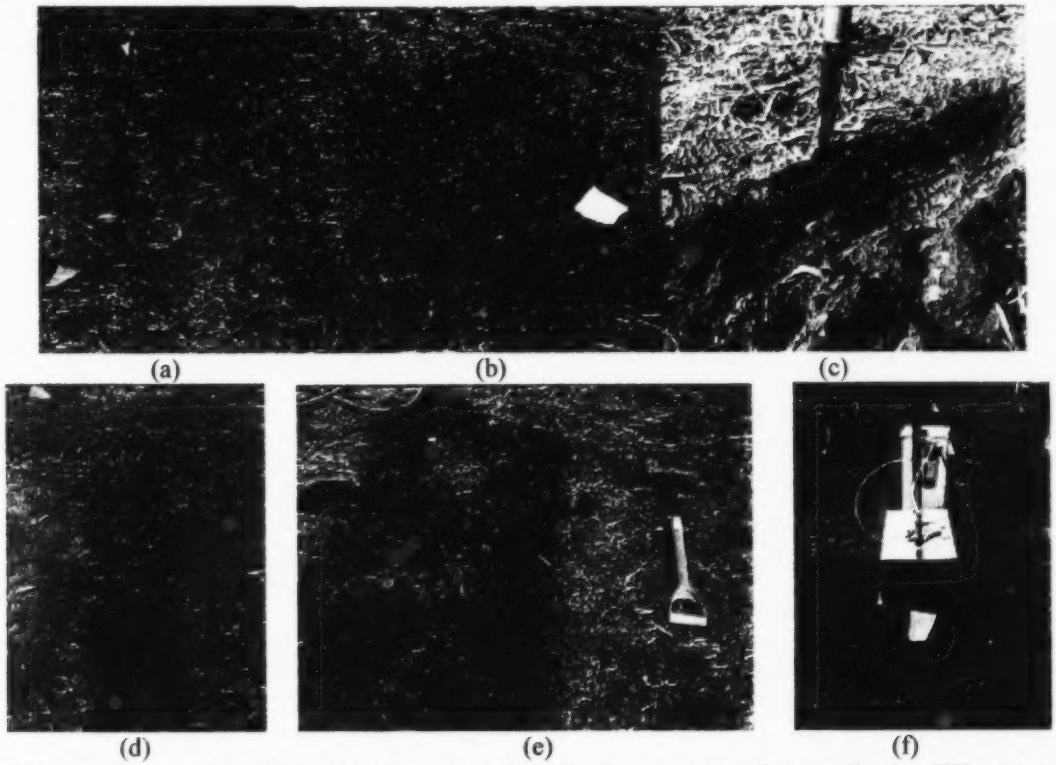

Figure 3.2.1 a) Liquid injection furrows b) Solid feedlot manure surface application (3X rate) c) Solid injection furrow d) After liquid injection (2X rate) e) Solid injection (2X rate before covering) f) Solid injection odour measurement (2X rate after covering).

3.3 Evaluation of odour intensity and dispersion from nasal ranging and Scentometer data

3.3.1 Nasal ranging

Trained odour assessors map odour intensities surrounding a production building, manure storage, or manure application site. The odour intensities are reported on a scale ranging from 0 to 5 (0 being no odour and 5 being an extremely strong odour). Calibration kits of N-butanol were developed according to standards set by ASTM (ASTM E544-99, 1975). N-butanol solutions were mixed and stored in jars with screw-on, Teflon lined caps. Each calibration kit included 5 jars. The n-butanol concentrations in water for the five levels of odour intensity are shown in Table 3.3.1.

The odour assessors attended a 90-minute classroom training session and a 30-minute field training session. In the classroom training session, assessors learned to calibrate their nose to the n-butanol intensity scale. During the sampling season, assessors were asked to perform a nose calibration at least twice a week. Assessors also completed an odour sensitivity test (St. Croix Sensory, Inc.) which scores an individual's odour sensitivity on a scale of 1 to 15 using a triangular forced-choice method with

increasing concentrations of N-butanol. Individuals with an odour sensitivity higher than 10 (too sensitive) or lower than 5 (not sensitive enough) were excluded from the field measurements.

Table 3.3.1 N-butanol concentration in water for the standard odour intensity scale

Intensity Scale	Description	N-butanol concentration (ppm)
0	No odour	0
1	Very faint odour	250
2	Faint odour	750
3	Moderate odour	2,250
4	Strong odour	6,750
5	Very strong odour	20,250

Field assessment began during or immediately after completion of manure application. The general weather conditions were recorded as well as general topography, type of application equipment, land location and manure information. Wind speed and direction were measured and recorded at each sampling location. Each assessor took 10 intensity readings in 10 minutes and 1 offensiveness reading at each location.

For the first five field sessions, the assessors followed the line formation and six degrees of separation used by odour assessors in Alberta (AAFRD, 2006). This resulted in a triangular shaped map of odour intensities downwind of the application site. This formation proved to be impractical for wide odour plumes and for mobile odour sources. Since the goal was to obtain information on the maximum odour intensity and the location where it occurred downwind of an application site, the field protocol was modified to focus on the odour intensity in the centerline of the plume where the maximum odour intensity would theoretically occur. Since the position of the center of the plume may vary with time (due to movement of equipment or a slight shift in wind direction), the assessors began in the downwind direction and moved toward the edge of the application site while maintaining a separation of 20 to 40 m (refer to Figure 3.3.1).

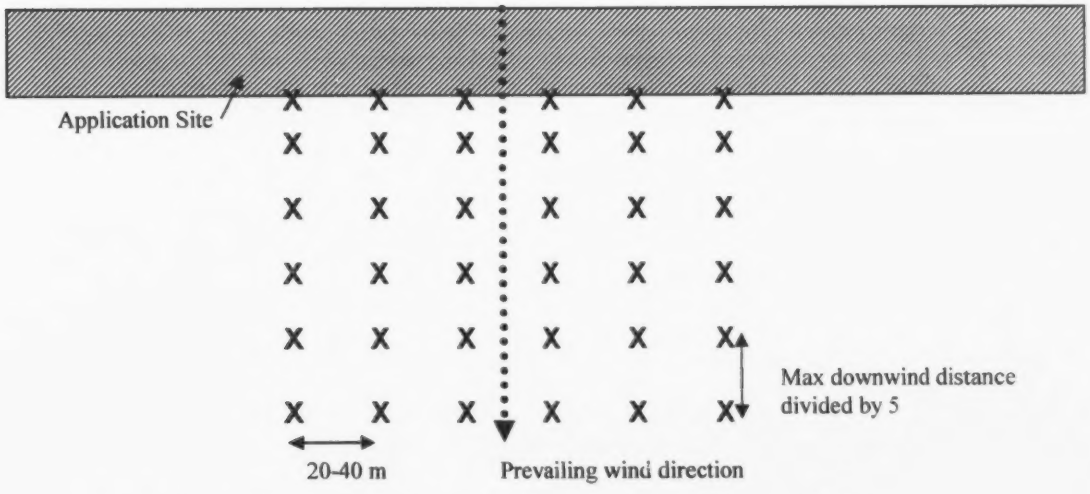

Figure 3.3.1 Diagram for modified Nasal Ranger field positions (not to scale).

In addition, the target maximum distance downwind (800 m) was often difficult to achieve due to physical obstacles or barriers such as trees, mature crops, large sloughs, etc. When the maximum achievable downwind distance was less than 800 m, several preliminary intensity measurements were obtained as close to the 800 m distance as possible (depending on the obstacle). In all cases where an obstacle restricted measurements, the odour intensity at 800 m was zero.

3.3.2 Scentometer

In addition to nasal ranging, odour dilution to threshold ratios were determined by means of the Scentometer™ from St. Croix Sensory Inc. The Scentometer™ allowed odour concentration readings to be collected directly in the field and provided instantaneous results. The odour sensitivity of all the odour assessors was determined by the odour sensitivity test kit from St. Croix Sensory Inc. and the individual with the highest score (most sensitive) was asked to take measurements using the Scentometer™.

The protocol provided with the Scentometer™ was modified slightly to improve the accuracy of measurements in low odour concentration environments. Instead of breathing through the unit at the prescribed rate for one full minute, only two sniffs at the proper rate were then required for each measurement. Additionally, the resting or cleansing breaths between readings could be completed at a normal breathing rate rather than at the prescribed rate. Finally, in low odour concentration environments, the tests began at lower dilution to threshold cartridges (7 or 15 rather than 60) to minimize the time required to complete the test.

4. RESULTS

4.1 Evaluation of existing protocols and development of new ones

4.1.1 Existing methods and protocols

A detailed review of existing methods and protocols for the determination of surface emissions of gases and odours was completed and the results are presented in Appendix 8.1.

4.1.2 Development of new methods and protocols

The review of literature (Appendix 8.1) indicated that a dynamic flux chamber or a wind tunnel were best suited to collect surface odour emissions resulting from the land application of manure. However, the optimal size, shape and operating flow rate of such flux chambers were not well defined in literature and needed to be determined before the field trials.

4.1.2.1 Chamber calibration

The calibration box designed and built for this project allowed for the testing and calibration of two types of dynamic chambers and of a wind tunnel. The airflow rate inside the dynamic chambers did not affect the CO_2 flux from the calibration box and it was determined that 0.000944 or 0.001416 m^3/s (2 or 3 cfm) flowrates provided the best flux estimations. Both dynamic chambers provided reproducible results but both chambers underestimated the CO_2 flux slightly. The calibration work showed that the use of a wind tunnel for collection of emissions from surface applied manure was not recommended because the high flow rate in the wind tunnel required to simulate typical wind speeds resulted in highly diluted samples for which the accurate determination of gas concentrations was very difficult. Based on the observations made during these calibration tests, the rectangular dynamic chamber with a sweep air flow rate of 0.944 L/s provided the simplest, most reliable flux measurements.

4.2 Evaluation of odour emission from surface emission data

4.2.1 Preliminary Plot Testing

The odour emissions results from the preliminary plot trial show that the dynamic flux chamber was well suited to make these measurements. The surface odour emissions immediately after a simulated surface application of 6,000 gal/acre (56 m^3/ha) were 40 and 39 OU/m^2-s (reps 1 and 2) while the incorporated odour emissions were 34 and 33 OU/m^2-s.

4.2.2 Full Factorial Plot Testing

Odour emissions from the full-factorial plot trial using the PAMI injector truck were significantly lower than results obtained from the preliminary plot tests (1 to 2 OU/m^2-s versus 35 to 40 OU/m^2-s). This may have been due to the high error associated with the air flow rate measurement in the preliminary plot testing. The equipment was modified to increase the accuracy of the air flow measurement for subsequent testing.

In general, the odour emission rate increased with application rate for the surface applied manure, but there was no trend between application rate and odour emission rate for the injected manure. The odour emission results are outlined in Table 4.2.1.

Table 4.2.1 Odour emission results from plots using PAMI injector truck.

	Odour Emission (OU/m^2-s)
Overall dairy	1.06
Overall swine	2.16
Overall injected	1.25
Overall surface	2.00

Based on the statistical analysis (Minitab v.15), the odour emissions from the swine manure were significantly higher than the emissions from the dairy manure (P=0.000). Also, the emissions from the surface applied manure were significantly higher than the emissions from the injected manure (P=0.002). However, the application rate did not statistically affect the odour emission rate. There were no statistical differences among the hedonic tones for application rate, application method or type of manure, although the trend (P = 0.052) showed that the injected plots produced slightly more pleasant odour samples than the surface plots.

The "simulated" application plots yielded similar results. Odour emissions from liquid manure were significantly higher than odour emissions from solid manure (P=0.000), but the overall odour emissions from all the injected plots (both types of solid and both types of liquid) were not significantly different from the odour from the surface applied plots. In three of the four treatments, the odour emissions from the injected plots were lower than emissions from the surface plots, but the high variability of the odour data resulted in the conclusion that the overall differences were not significant. Additionally, there were no significant differences between the odour from dairy and liquid swine manure, nor was there a difference between the feedlot and solid swine manure. A summary of the odour emissions from the plots are presented in Table 4.2.2. For the simulated plots, odour samples from the solid manure plots were more pleasant than samples from the liquid manure plots and samples from the injected plots were more pleasant than samples from the surface applied plots.

Table 4.2.2. Odour emission results from "simulated" application plots.

Liquid Manure	OU/m²-s	Solid Manure	OU/m²-s
Dairy	1.40	Feedlot	0.80
Swine	1.34	Swine	0.58
Injected	1.43	Injected	0.52
Surface	1.31	Surface	0.92
Overall	1.37	Overall	0.69

*Overall injected odour emissions = 0.86 OU/m²-s and overall surface emissions = 1.09 OU/m²-s.

For the solid manure plots, injection decreased odour emissions by about 64% in the swine plots and by 15% in the feedlot plots. For the dairy plots, injection decreased emissions by 57% but for the liquid swine plots, injection actually increased emissions by 65%. However, the odour concentrations of 3 samples from the liquid swine injected plots were extremely high (1 from the mid rate and 2 from the high rate) and may have been due to contamination in the olfactometer. If these data points are excluded from the analysis, however, the average odour emission from the liquid swine injected plots is still higher than average emission from the liquid swine surface application.

Additionally, for the mid and high rates of injected liquid manure, there was significant pooling of manure on top of the furrows because the furrows were not large enough to accommodate the amount of manure applied. Even though the manure infiltrated quickly, the odour emissions immediately after application of the mid and high rates would be similar to emissions from surface applied liquid manure. However, the solid manure was always completely covered by the furrows, leaving no manure on the soil surface during measurement. This may explain the increased reduction in odour emissions from injected solid manure over injected liquid manure.

The overall results of the simulated application plots are graphically represented in Figure 4.2.1.

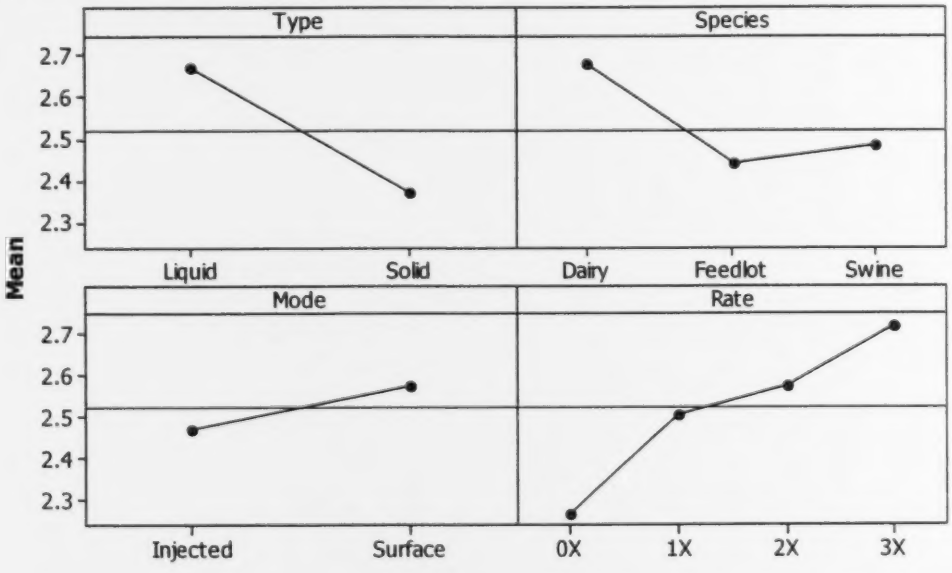

Figure 4.2.1. Odour concentration results (logarithmic values) from the simulated application plots for manure type, manure species, application mode and application rate.

4.3 Evaluation of odour intensity and dispersion from nasal ranging and Scentometer™ data

4.3.1 Nasal Ranger Results

Detailed information on the results obtained by the nasal rangers is included in Appendix 8.3. Table 4.3.1 is a summary of these results, outlining the maximum and average odour intensities observed at various distances downwind of surface and injected manure application sites. Unfortunately, due to delays in the fabrication of the solid manure injector prototype at PAMI, no intensity data could be collected downwind of solid injected sites.

Table 4.3.1. Summary of odour intensity results obtained by nasal rangers.

Type of manure application	Maximum distance downwind	Maximum odour intensity at maximum distance	Average odour intensity at maximum distance	Atmospheric stability class
Liquid injection[1]	360	3.0	1.3	B (moderately unstable)
Liquid injection[2]	800	3.0	1.5	A-B (very to moderately unstable)
Liquid injection[3]	300	1.0	0.1	D (neutral)
Liquid broadcast[4]	600	3.0	1.2	C (slightly unstable)
Liquid broadcast[5]	460	2.0	1.0	A-B (very to moderately unstable)
Solid broadcast[6]	600	5.0	2.5	D (neutral)
Solid broadcast[7]	800	0.0	0.0	C (slightly unstable)
Solid broadcast[8]	480	3.0	1.1	B-C (moderately to slightly unstable)
Solid broadcast[9]	650	3.0	1.1	C (slightly unstable)

[1] Liquid swine injection with drag hose at Elstow (Fall, 2005).
[2] Liquid swine injection with drag hose at Floral (Spring, 2006).
[3] Liquid swine injection with drag hose at Elstow (Fall, 2006).
[4] Liquid swine broadcast at Germs' (Summer, 2006).
[5] Liquid swine broadcast at Germs' (Summer, 2006).
[6] Solid swine broadcast at Germs' (Fall, 2006).
[7] Solid feedlot broadcast at U of S feedlot (composted feedlot manure) (Spring, 2007).
[8] Solid swine broadcast at Germs' (Summer, 2007).
[9] Solid swine broadcast at Germs' (Summer, 2007).

For the solid broadcast site 6, the high intensity measurements were very intermittent (approximately 4 or 5 spikes in a 3 hour span). Several intensity zero readings were observed at 800 m downwind, but the measurement period may have missed the spikes in odour experienced at 600 m downwind. The weather was cool and the wind speed was high (gusting up to 7.5 m/s) for location 6 in contrast to the hot, calm conditions for locations 8 and 9, a possible reason for the higher intensities observed at location 6 compared to locations 8 and 9.

Based on these results, there is little chance of exceeding the intensity 2 odours deemed acceptable for neighbours in the community within the 800 m separation distance recommended by livestock regulators in Saskatchewan. However, in the right atmospheric conditions, it is possible that odour plumes may carry odour intensities of 2 or more up to 1 km downwind of the application site. This is most likely to occur during solid broadcast applications or large-scale, high-rate liquid injection applications.

4.3.2 Field Olfactometer Results

The odour dilution to threshold results obtained with the field olfactometer for the manure application sites are presented in Table 4.3.2. Whenever possible, the odour intensity as observed by the trained odour assessors at that location is also listed (values in brackets indicate the standard deviation of the intensity). At site 2, the field olfactometer operator was located in the center of the plume and at site 3, the operator was approximately -18° from the centre of the plume.

In general, the odour dilution to threshold results agree reasonably well with the odour intensity values. The downwind edge location resulted in higher D/T readings (between 15 and 60) and the D/T values

decreased to 1 as the distance from the source increased. One problem with the field olfactometer is that the short sampling period (two 'sniff's every minute or so) may miss any spikes in odour that may occur as the odour plume wafts over the assessor. Increasing the number of readings taken at each location could help account for this. As shown in the results of Table 4.3.2, the D/T values at a given location can vary between 1 and 15. The appropriate presentation of this data can be a challenge since only averaging the values does not accurately represent the odour concentration. Listing all the D/T values recorded at each location shows the range and frequency of D/T values encountered, which more accurately represents the odour at that location. Past studies have used only the highest odour dilution to threshold value when analyzing the data obtained with the field olfactometer (Hamel et al. 2004).

Table 4.3.2 Odour dilution to threshold (D/T) results.

Site	Date	Treatment	Location	D/T	Manure Info	Intensity
Dixon	Oct 5/05	Liquid injection	Upwind edge	1 (4 readings)	farrow to finish	
			Downwind edge	4 (4 readings)	1 year EMB	
			500 m downwind	1 (4 readings)	tanker truck injection	
Elstow (site 1)	Oct 22/05	Liquid injection	Downwind edge	15 (4 readings)	farrow to finish 1 year EMB drag line injection	4.08 (0.66)
St. Denis	May 9/06	Liquid injection, 6 hrs after	Downwind edge	7 (2 readings)	farrow to finish 1 year EMB drag line injection (9,000 gal/acre)	2.70 (0.48)
Floral (site 2)	May 18/06	Liquid injection	800 m downwind	1 (3 readings)	farrow to finish	1.48 (0.22)
			640 m	4 (3 readings)	1 year concrete tanks	2.03 (0.46)
			480 m	4 (3 readings)	drag line injection (6,000 gal/acre)	2.50 (0.38)
			320 m	15, 1, 15, 7		3.68 (0.46)
			160 m	15, 15, 15, 7		4.33 (0.49)
			Downwind edge	30 (3 readings)		4.83 (0.15)
Germs (site 3)	June 2/06	Liquid surface	600 m downwind	1 (3 readings)	grow-finish	1.23 (0.45)
			480 m	1 (3 readings)	1 week concrete tank	1.08 (0.10)
			360 m	1 (3 readings)	splash plate application	1.48 (0.62)
			240 m	15, 7, 1, 15, 4, 4		2.13 (1.10)
			120 m	1, 1, 4, 4, 4		2.35 (1.07)
			Downwind edge	15 (3 readings)		2.35 (0.65)
Germs (site 4)	July 14/06	Liquid surface	165 m downwind	1 (3 readings)	see above	1.45 (0.51)
			Downwind edge	60 (3 readings)		4.03 (0.85)
Elstow (site 5)	Oct 20/06	Liquid injection	Downwind edge	15 (3 readings)	farrow to finish 1 year EMB drag-line injection	3.90 (0.57)
Germs	Oct 25/06	Solid broadcast	600 m downwind		grow-finish	
			between applications	60, 30, 2, 15, 15	1 year hoop structure bedding	~2.0-3.0
			during application	60, 30, 30	box spreader	~3.0-5.0

5. CONCLUSIONS AND RECOMMENDATIONS

Dynamic flux chambers were used in this study for surface odour emission measurement. A sweep air flow rate of 0.944 L/s proved to work well for the magnitude of odour emissions arising from manure spreading activities. However, care must be taken to ensure an accurate measurement of the sweep air flow rate as this source of error can significantly increase the error associated with the odour flux measurement. In addition, sweep air flow rates in excess of 0.944 L/s have the potential to dilute the

sample beyond measuring capabilities of the olfactometer. Whenever possible, it is recommended to obtain baseline odour emission data to better select an appropriate sweep air flow rate as a rate of 0.944 L/s may also result in odour concentrations being too high to be measured by the olfactometer in certain situations. Also, the field olfactometer (Scentometer™) worked very well for field measurements of odour concentration. The simple and instant results make the Scentometer™ a great option for future work with odour plumes downwind of manure application sites.

The results of the plot studies indicate that odour emissions from injected plots were up to 64% lower than emissions from broadcasted applications. Injection seemed to have a larger impact on reducing odour emissions from solid manure than liquid manure. In fact, odour emissions from injected liquid swine manure were actually 65% higher than emissions from surface applied liquid swine manure. Odour emissions from solid manure were 50% lower than from liquid manure. In general, odour emissions from liquid and solid manure increased with higher application rates but not significantly until the application rate reached two to three times the normal annual application rate. For the plots applied with the PAMI truck, the odour emissions from the swine manure were higher than the emissions from the dairy manure, but this difference was not significant in the simulated application plots. In addition, greenhouse gas emission data suggests that injection of both liquid and solid manure does not significantly increase the total emissions of carbon dioxide equivalents.

The odour intensity data collected during this study is somewhat contradictory and less reliable than the surface odour emission data. In general, the odour intensities downwind of the liquid broadcast sites were lower than the odour intensities downwind of the liquid injection sites. However, varying application rates and the size of the area the manure was applied to may have influenced these conclusions. The liquid injection sites were over 30 hectares at approximately 75 m^3/ha while the liquid broadcast sites were about 5 hectares at approximately 40 m^3/ha.

Additionally, the plot studies indicated that emissions from solid manure plots were lower than emissions from liquid manure plot while full-scale solid manure applications generally produced higher intensities than liquid applications. However, the spikes in odour surrounding full-scale solid applications were very intermittent with several readings of zero intensity following each intensity spike. Although no high intensity odours were observed beyond 600 m downwind, it is possible that solid broadcasting can produce high intensity odours up to 1 km downwind in neutral or stable atmospheric conditions. Based on the surface emission results, injection of manure does reduce the odour emissions, but the odour intensity data collected in this study does not reflect that decrease.

Based on the results from this study, injection of manure is an effective way to reduce the overall odour emissions from manure spreading without significantly increasing the overall emissions of carbon dioxide equivalents (GHG's). However, other factors associated with manure injection, such as the increased power requirement and soil disturbance, must be considered when evaluating the overall impact of manure injection versus surface application. The results also indicate that while injection of manure lowers the surface emissions on a plot scale, sub-surface application may not significantly lower the odour intensity downwind of application sites.

6. ACKNOWLEDGEMENTS

Saskatchewan Agriculture and Food's support of this project has been gratefully acknowledged in all publications arising from the project and all communications with producers and academia regarding the project.

The cooperation and assistance of the following groups/individuals is also greatly appreciated:

- ✓ St. Croix Sensory Inc.
- ✓ Local producer Mr. John Germs
- ✓ Sand's Custom Application
- ✓ U of S Farm Manager Mr. Doug Bradley
- ✓ U of S Dairy Manager Ms. Marlene Fehr (and the dairy barn staff)
- ✓ Prairie Swine Centre Inc. (Floral and Elstow)

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8. APPENDICES

8.1 Evaluation of existing protocols for surface emissions of gases and odours

8.1.1 Odour Emissions Arising from Land Application of Manure

Research at the University of Alberta (Navaratnasamy et al., 2004) compared odour emissions calculated using samples collected from a wind tunnel and a vented chamber technique. Due to the laminar and turbulent air flow in the wind tunnel and flux chamber respectively, the emission rate at an air flow of 3.8 L/s in the vented flux chamber corresponded to the emission rates measured by the wind tunnel with a flow rate 30 L/s. Smith and Watts (1994) reported that a comparison of the wind tunnel and the flux hood showed the flux hood consistently gave results which were half those obtained with a wind tunnel. The main reason for this is the suppression of the emission within the flux hood as a result of the very low surface wind speed in the hood and the subsequent lack of turbulent transport away from the emitting surface. Thus, the preferred method of direct measurement of point emission rates from extensive surfaces is the wind tunnel operated at a wind speed equivalent to the ambient conditions.

Nasal rangers, or trained human receptors, are gaining popularity for odour intensity determination and the training of nasal rangers and field protocols have been established by the University of Alberta odour team. Researchers working with Alberta Agriculture, Food and Rural Development are also assessing the odour emissions after surface application of liquid manure and composted manure.

Previous research in the United States (Hanna et al., 2000) investigated the effects of five different incorporation tools on the odour emissions after liquid swine manure application. The researchers used the wind tunnel method to collect surface samples after manure application on test plots, and most methods involving soil incorporation reduced odour levels by 20 to 90% from the odour level emitted after surface broadcast application. Additionally, odour levels reduced quickly with time, and after 24 hours, were statistically indistinguishable with odour from untreated soil. However, odour intensity surrounding the test sites were not determined, and the climate and topography conditions are not the same in Saskatchewan.

Research in British Columbia (Lau et al., 2003) compared odour concentrations and odour emission rates due to pig manure application to grass-land using a sub-surface deposition system and a conventional splash-plate applicator. Samples were collected using a flux chamber 0.5, 1.5 and 2.5 hours after application and showed the sub-surface deposition applicator odour emission rate was reduced by 8 to 38% compared to the conventional splash-plate system. Again, the research results indicated odour emissions decreased significantly only one hour after application, but odour intensity was not determined and emissions from grass-lands are significantly different from emissions from agricultural soils.

Pain et al. (1991) used a simplified micrometeorological technique to collect odour samples from a surface applied with pig and cattle slurry. The slurry was either left on the soil surface as a control or incorporated by means of a plough, rotary harrow or rigid tines. On arable land, ploughing immediately after application reduced the rate of odour emission during the first hour by 85% and rotary harrowing reduced it by 45% whereas the result when rigid tines were used was similar to the control. A worthwhile reduction (52%) in total odour emissions over 48 hours was achieved only by immediate ploughing. No reduction in odour emission was detected when incorporation, by any means, was delayed for 3 to 6 hours after slurry application.

8.1.2 Methods of Gas Collection

Agricultural emissions have been collected and measured a variety of ways. Non-point source emissions from a large area (such as a field that has been treated with manure) may be collected via static chambers (Chadwick and Pain, 1997; Kabwe et al. 2002; Marshall and Debel, 1980; Scott et al., 1999; Sherlock et al., 2002; Thornton et al., 1996; etc.), flux chambers (Ball et al., 2002; Ginting et al., 2003; Lau et al., 2003; etc.), wind tunnels (Braschkat et al., 1993; Hanna et al., 2000; Jiang and Kaye, 1996; Lockyer, 1984; Meisinger et al., 2001; Misselbrook et al., 1997; Pain et al., 1991; Rahman et al., 2004; Sommer and Olesen, 1991, etc.), micrometeorological techniques (Gao et al., 1997; Hansen, 2004; Hargreaves et al., 1996; Huijsmans et al., 2001; McInnes et al., 1986; Phillips et al., 2000; Wilson et al., 1983, etc.) or a combination of one or more of these techniques.

Greatorex (2000) provided a complete summary of all these techniques and their applications. For non-point source emissions from treatment plots, this author suggests using dynamic chambers since they are suitable for treatment comparisons, minimize disturbance and allow for more sampling frequency (if automated). They are also inexpensive to fabricate and operate.

Sherlock et al (2002) utilized different methods for different gases. Since ammonia is very reactive with water compared with methane (CH_4) and nitrous oxide (N_2O), the elevated ammonia (NH_3) concentration in a static chamber will reduce NH_3 emissions from the soil covered by the chamber. The NH_3 emissions, therefore, were measured with a micrometeorological mass balance technique that does not affect the NH_3 concentration above the soil amended with slurry. In contrast with NH_3, static chambers are the preferred current method for measuring surface fluxes of both CH_4 and N_2O since these gases are less reactive with water and are much less affected by increases in chamber headspace concentration. Also, in contrast to NH_3, it is generally very difficult to detect the small concentration gradients of N_2O and CH_4 above the soil surface when these gases are being emitted. This is necessary for implementing micrometeorological techniques. Nevertheless, when comparisons between methods have been possible, little if any difference is observed between N_2O emissions measured with a micrometeorological technique and static chambers (Fowler et al 1997). Consequently, Sherlock et al (2002) utilized static chambers to measure N_2O and CH_4.

8.1.2.1 Static Chambers

The static chamber method involves allowing gas emissions to collect in a container of known volume for set periods of time. Samples are drawn at known intervals and the concentrations of the gases are measured and plotted versus time. The gas emission rate and concentration at time zero can then be calculated. For example, Sherlock et al 2002 used the static chamber method to evaluate methane and nitrous oxide emissions from pasture land applied with slurry. Steel cylinders (24 cm diameter) were pushed into the soil. Five cylinders were placed in the slurry treated plot and four cylinders were located on untreated soil upwind of the plot. Changes in headspace CH_4 and N_2O concentrations were used for calculating gas fluxes. Gas samples were collected with 50 mL syringes at 0, 10 and 20 min after lid closure (Sherlock et al, 2002).

8.1.2.2 Vented Chambers/Flux Chambers/Wind Tunnels

The flux hood is a sealed chamber open at the base and which is placed on the gas or odour emitting surface for the purpose of sampling the emissions. During operation, clean dry air is forced under pressure into the hood at a fixed slow rate (2 L/min). Within the hood, this air is mixed with the emitted odours by the physical layout of the device (in some hoods the mixing is aided by an impeller within the hood). The sample is drawn from the chamber when required at a rate of 1 L/min. Excess air is expelled to the atmosphere through a small vent in the hood, this vent also serving to maintain the pressure in the hood

close to atmospheric pressure. Assuming complete mixing between the emissions and the sweep air, the emission rate, E, can be calculated from the concentration, C, of the exhaust gas using a simple continuity equation: E = QC/A. Particular care is required to ensure that the pressure inside the chamber is identical to the outside pressure. Other factors affecting the rate of emissions as sampled by a flux hood are:

- the relatively small area of emitting surface enclosed by the hood;
- the suppression of the turbulent transport mechanism which under ambient conditions transports the emissions away from the emitting surface, and
- the imperfect mixing of the emissions with the sweep air.

Wind tunnels are portable, open-bottomed enclosures which are placed over the emitting surface. Ambient or filtered air is blown or drawn through the tunnel to mix with and transport the emissions away from the emitting surface. The selection of the appropriate wind speed to use in a wind tunnel is critical and should be reported whenever emission results from a wind tunnel are published.

Gao et al (1997) includes a comprehensive discussion on the assumptions required for flux chamber use as well as their advantages and disadvantages. The assumptions that must be made for flux chambers include:

- Airflow in chamber must be steady-state (i.e. the rate of ail flow is not a function of time);
- Gas flux must be uniform over the entire covered surface and relatively constant during the sampling interval;
- The in-coming and out-going air streams must be well mixed, and
- The diffusive flux must be dominant and the advective mass flow is negligible.

Advantages of using dynamic chambers include:

- The potential to maintain conditions within the chamber nearly the same as those in the surrounding field.
- The determination of a significant concentration buildup of the target gas in the chamber, since the target gas emitted from the covered soil into the chamber is continuously carried away to the outside environment by a clean in-coming air stream.

Disadvantages of using dynamic chambers include:

- The air flowing in the chamber may change the pressure gradient between the soil-gas phase and the chamber interior. Such a change in the pressure gradient may create an advective mass flow of the target gas, which may be different from that created by the surface winds outside the chamber. For example, when the air in the chamber flows relatively fast and the wind outside the chamber is relatively slow, the flowing air in the chamber may create a pressure deficit, which produces an additional mass flow from the soil into the chambers. This pressure deficit may result in an overestimate of the emission from the uncovered soil.
- Another problem is associated with the aerodynamic behavior or air-flow pattern. If the chambers inlet and outlet are not designed and installed properly the flowing air through the chamber may not sweep over the entire covered surface, leaving local stagnant air zones inside the chamber. In addition, the air flow may have vertical components (downward or upward) that will exert a direct positive or negative pressure upon the covered soil surface. Both stagnant zones and vertical airflow components can cause a spatially variable surface flux.

8.1.2.3 Micrometeorological Techniques

Sherlock et al (2002) provided a good description of a micrometeorological technique. The mass balance method equates the average surface flux density of NH3 from the circular plot amended with pig slurry to the difference between the integrated horizontal flux at a known downwind distance and that at the upwind edge of the field. With passive Leuning samplers mounted at several heights on masts placed at the upwind edge and at the center of the plot (radius 20 m), the net horizontal flux was derived. The samplers were mounted on a mast in the center of the field at .2, .4, .8, 1.2, 2.4 and 3.6 m above the soil surface. Background measurements were made with samplers placed at .4 and 1.2 m on a mast located on the upwind side of the treated area.

The "standard comparison" micrometeorological method was described in Wulf et al. (2003a). The Svensson method (dynamic chambers) involves the measurement of equilibrium NH3 concentrations inside and outside of dynamic chambers on every plot, followed by micrometeorological calculations. For the "standard comparison" method, only one passive sampler per plot is needed and emission rates are calculated by simple comparison of passive sampler concentrations on standard and treatment plots

8.1.3 Greenhouse Gas Emissions

Christensen et al (1996) monitored N_2O emissions using micrometeorological and chamber techniques (3 sizes of chamber and a sweep flow rate of 1.5 L/min). The chamber measurements over 9 days showed a flux of 162-202 μg N_2O-N /m^2-h from wheat stubble. The authors concluded that there was no bias between the different approaches used to measure the N_2O emission and that the precision of the measurements was determined by the spatial variability of the N_2O emissions at the site and the variability inherent in the individual techniques.

Ginting et al (2003) monitored GHG emissions and soil indicators for 4 years after fertilizer, solid beef cattle manure and compost application using the vented surface gas chamber technique. The authors reported that GHG emissions were unaffected by manure application and the residual effects of manure and compost four years after application had no negative influence on soil carbon and nitrogen storage and global warming. Soil receiving manure or compost had similar carbon dioxide (CO_2) emission as the control or fertilized soil as early as 1 month after application. CH_4 fluxes were not different among treatments at each sampling time and there was no consistent pattern of fluxes. N_2O fluxes were not different among treatments at each sampling time except 1 month after application.

Sherlock et al (2002) examined ammonia, methane and nitrous oxide emissions from pig slurry applied to pasture for 90 days after application. The researchers used the static chamber method for N_2O and CH_4 fluxes and mass balance micrometeorological methods for ammonia emissions. The pig slurry was applied to the land at a rate of 60 m^3/ha. The method of application was not published. Methane emission commenced at the very fast rate of 39.33 g C/ha/h immediately after application and decreased to 10 g C/ha/h within 6 h. At all times, N_2O emissions from the slurry-treated plot were significantly greater than those from the untreated control plots.

Wulf et al. (2002a) and (2002b) discuss the effect of application technique of slurry on ammonia and GHG emissions up to 96 hours after spreading. Again, NH_3 emissions were measured by passive sampling and mass-balance micrometeorological "standard comparison" method. Substrates (slurry and digested substrate) were applied at a rate of 30 m^3/ha by splash plate, trail hose, trail shoe and injection (10 cm deep). The injection system was an actual mechanical system while the others were simulated by hand. The more the substrate was incorporated into the soil or applied near the soil surface on the grassland site, the less NH_3 was lost. Injection of the soil substrate reduced losses to less than 10% of applied NH_4 on both sites, whereas losses after splash plate application amounted to more than 30%. Trail

shoe application on grassland performed as well as injection. Harrowing on arable land also reduced emissions efficiently, if harrowing occurred within the first two hours after application. NH_3 emission reduction, achieved by injection, is at least compensated by increased N_2O emissions. Results indicated that on arable land, trail hose application with immediate shallow incorporation and on grassland, trail shoe application bear the smallest risk of high GHG emissions when fertilizing with co-fermented slurry.

Wulf et al (2002b) discussed two possible sources of CH_4 emissions. Emissions that occur immediately after application can be assigned to the release of dissolved CH_4 being produced prior to application during storage of the substrate. The second possible source is via methanogenesis in the soil, as anaerobic conditions might be promoted through this application technique causing CH_4 production resulting in a higher overall emission compared to surface applied substrate. N_2O emission varied clearly with time and space. The temporal pattern of emissions strongly depended on environmental conditions during the experiment. In terms of CO_2 equivalents, the increase in N_2O emissions after injection might be as high as the reduction of NH_3 losses or, as in the case of injection on grassland, might even increase overall GHG emissions. Nevertheless, it should be considered that detrimental effects of NH_3 also include acidification and eutrophication (as well as odour).

Weslien et al (1998) reported slightly, but not significantly, higher emissions after band-spreading followed by harrowing compared with band-spreading, trenching, and shallow injection (6 cm). Slurries applied to 9-m^2 plots at a rate of 114 kg N/ha. Closed (static) chambers covering 0.25 m^2, 10 cm deep into soil were used for emission collection. Sampling times varied over course of 6 weeks due to expected reduction in gas fluxes. The highest emissions of methane took place immediately after spreading on both sites and were hardly detectable during the following measurements for most of the treatments.

8.1.4 Odour Emissions

Edeogu et al (2001) and Laguë et al (2004) utilized the vented chamber technique for measuring odour emissions from manure storage surfaces. Laguë et al (2004) used 0.94 L/s (2 cfm) flowrate while Edeogu used 1 L/s flowrate. Differing airflow rates have been noted to be a contributor to the various emission rates found in literature. Guo et al (2001a) and Zhou et al (2005) summarize the air dispersion models applicable to odour dispersion modeling while Guo et al (2001b) and Jacobsen et al (2001) discuss the impacts of weather stability on odour dispersion.

Hanna et al (2000) investigated the effects of application technique of liquid manure on odor emission, along with residue cover and crop yield using the wind tunnel method. Samples were collected immediately after and one day after application. Incorporation or injection of the manure decreased odour emission by 20 to 90% and odours after one day from the treated soil was statistically indistinguishable from the untreated soil.

[Note that odour emissions with units of OU m/s are equivalent to emissions with units of OU/m^2-s when the odour concentration units are assumed to be OU/m^3].

Smith and Watts (1994b) reported cattle and poultry manure had odour emission rates at 22 OU m/s three hours after spreading and 25 OU m/s one hour after spreading. There was little difference between application treatments after four hours. Pain et al (1991) reported that, one hour after spreading, pig slurry had odor emission rates of 504 OU m/s as compared to 31 OU m/s four hours after spreading using micrometeorological methods. A worthwhile reduction (52%) in total emission (odour units) over 48 h was achieved only by immediate ploughing. No reduction in total emission was detected when incorporation, by any means, was delayed for 3 to 6 hr after slurry application.

Phillips et al (2000, 2001) analyzed shallow injector, deep injector, trailing or hanging hoses, traveling irrigation gun and splash plate using a surface isolation flux chamber with 10 L/min airflow rate (Odoflux, Odotech Inc, Montreal QC) and olfactometry. Their results, including standard deviations, are shown in Table 8.1.1.

Table 8.1.1 Effect of application method on odour emission rate and variance (Philips et al., 2000 and 2001).

Application Method	Odour Emission (OU per L of manure applied)	Odour Emission (standard deviation)
Splash plate	249,000	130,000
Shallow injector	133,000	94,000
Deep injector	182,000	100,000
Hoses	35,000	27,000
Irrigation gun	6,520,000	5,690,000

Lau et al (2003) investigated odour measurements for manure spreading using a subsurface deposition applicator and liquid swine manure using a flux chamber operated at 10 L/min. A splash-plate applicator and sub-surface deposition system were used for manure application. The effect of time after application up to 2.5 hours was investigated. There was a statistically significant difference in odor strength between the two methods of manure application. Towards the end of the 1.5- and 2.5-hour observation periods, the gap between the odors from the two methods had decreased but there remained a difference of 8 to 25%. The subsurface depositions system applicator reduced odor by 8% to 38% compared to that of the conventional splash-plate applicator.

Pain et al (1988) published a correlation between odour and NH3 emissions following application of pig or cattle slurry to land. The effect of time up to 5 hours on emissions after application was investigated using a wind tunnel and air speeds of 1 and 3 m/s.

Rahman et al (2004) reported on the effects of sweep injection tools on soil surface profile, manure exposure and odour emissions using 3 tools, 3 depths, 2 speeds and 2 moisture contents. A wind tunnel with a flowrate of 0.3 m/s and vacuum pump used to collect odour samples in bags and olfactometer used for concentration analysis. Odor emissions increased significantly with injection depth but not with application rate. The odour concentrations were highly variable (CV = 90 – 128%) and had an average of 723 OU/m3. This variability was affected by weather conditions, manure characteristics, soil conditions and soil residue cover as well as manure applied to the nearby by plots from previous applications. Odour emission rate increased significantly with increased injection depth. These unexpected results could have been attributable from a number of factors. For example, increased injection depth decreased the value of soil covering which might contribute to increased contact area between the manure and ambient air resulting in increased odor emissions. There was no correlation between odor emission rate and manure exposure.

Sommer and Huchings (2001) observed that at cold weather odor stayed near the ground surface and results in higher odor concentrations.

Smith and Watts (1994a and 1994b) examined odour emission rates from cattle feedlots and summarized the literature value comparison of odour emissions cattle feedlots between flux hoods and wind tunnels. Flux hoods resulted in odour emission between 0.11 and 2.0 OU m/s and wind tunnels resulted in odour emission measurements between 5 and 800 OU m/s. In addition, a review of the effect of type of manure and time after spreading on emission was summarized and is shown in Table 8.1.2.

Table 8.1.2 Effect of slurry type and time after spreading on odour emission rate (Smith and Watts 1994b)

Slurry	Time after spreading (hr)	Emission rate* (OU/m^2-s)	Source
Pig	4 to 48	31 to 8	Pain et al
Cattle	3 to 48	22 to 11	Pain et al
Poultry	1 to 48	25 to 5	Pain and Klarenbeck
Pig	1 to 60	504 to 14	Pain et al
Pig	1 to 48	221 to 3	Pain and Misselbrook

* Emission rate cited with units of OU m/s, which is equivalent to OU/m^2-s if the odour concentration units are assumed to be OU/m^3.

Smith and Watts (1994b) stated that evaporation of water from a drying soil provides a guide to the likely process of odour emission. It can be postulated that there will be a potential or maximum odour emission rate whose magnitude is determined by meteorological factors but with the actual emission rate at any time controlled by the rate of odour generation and transport to the emitting surface.

Smith and Watts (1994b) also examined the effects of time after spreading and sweep air flow rate in the wind tunnel on odour emissions. These results are summarized in Table 8.1.3.

Table 8.1.3 Effect of time after spreading and sweep air flow rate on odour emission rate (Smith and Watts 1994b)

Time after spreading (hours)	Sweep air flow rate (m/s)	Odour emission rate* (OU/m^2-s)
2	1	43
2	3	160
5	1	33
5	3	128

* Emission rate cited with units of OU m/s, which is equivalent to OU/m^2-s if the odour concentration units are assumed to be OU/m^3.

Additionally, Smith and Watts (1994b) studies odour emissions from cattle feedlots using two tunnel sizes (0.25 m^2 and 1 m^2). Data from the large wind tunnel was more variable than that for the small wind tunnel and the emission rates determined using the small tunnel were consistently higher than those from the large tunnel. The authors also noted that wind speeds must be specified whenever wind tunnel emission rates are cited and the rates should also operate wind tunnels at ambient wind speeds.

8.1.5 Other Emissions

Huijsmans et al (2001) examined the effects of application technique, manure characteristics, weather and field conditions on ammonia volatilization from manure applied to grassland using micrometeorological techniques. Cumulative volatilization for surface spreading was estimated to be 77% of the TAN applied, 20% for narrowband application and 6% for shallow injection. The TAN content of manure, manure application rate and the weather conditions significantly influenced the NH_3 volatilization rate. After 96 hours, NH_3 volatilization was negligible. In the model, about 50% of the variation in NH_3 volatilization was accounted for by application technique.

Van der Weeden et al (1996) employed wind tunnel methods for measurement of ammonia volatilization from land through simulated lab experiments. The authors noted that it is not valid to compare wind tunnel results with micrometeorological results since wind speed and other ambient conditions will fluctuate during micrometeorological measurements while ambient conditions (wind speed = 1 m/s) are

kept constant in a wind tunnel. A way around this would be to match wind speed in the tunnel to ambient conditions, however, this is often not practical.

Sherlock et al (2002) examined the effects of time after application on ammonia emissions. Two and a half hours after slurry application, NH_3 was lost at a rate of 4.7 kg N/ha/h. In the next 4-hour period, emission rate was half that. After 24 hours, NH_3 volatilization rates declined markedly. Wulf et al. (2002a) saw similar results, showing that cumulated estimates after 24 hours ranged from 88% of total emission after splash plate application on both arable and grassland surfaces and 70% after harrowing on arable land. The influence of application technique on NH_3 volatilization was already evident at the first sampling date (350 mg N/m^2-h for splash plate application).

Because NH_3 emissions are strongly influenced by highly variable environmental factors such as temperature, wind speed, and precipitation, it is indispensable to test a series of application techniques simultaneously to determine useful mitigation strategies (Wulf et al, 2002a).

8.1.6 References

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8.2 Flux chambers

Two types of flux chambers were evaluated for repeatability of results and capture efficiency: a circular flux chamber and a rectangular flux chamber (0.28 m^2 and 0.323 m^2 surface area respectively). To determine the optimum sweep air flow rate, the chambers will be tested with operating flow rates ranging between 0.000236 and 0.001888 m^3/s (0.5 and 4 cfm).

8.2.1 Circular Flux Chamber

The circular flux chamber was designed and built within the scope of a previous study (Laguë et al 2004) examining greenhouse gas and odour emissions from liquid swine manure storage facilities. The chamber was made of PVC tubing having an internal diameter of 600 mm and a length of 1,000 mm (Figure 8.2.1a). The top end of the chamber was closed by means of a PVC sheet 6.35 mm thick. The chamber contained two circular manifolds, also made of PVC, seen in Figure 8.2.1b). The clean air was distributed by the lower manifold which was approximately 150 mm from the emitting surface. The contaminated air was then collected by another manifold near the top of the chamber and evacuated to the exhaust pipe at the top of the chamber. A portable gas powered air compressor supplied fresh air to the chambers. The air from the compressor was passed through a charcoal filter and rotameter (VF VISI-Float VFB-90-BV) to regulate the flowrate to the chamber. Samples were drawn into Tedlar bags via a vacuum chamber through the sample collection manifold in the exhaust pipe.

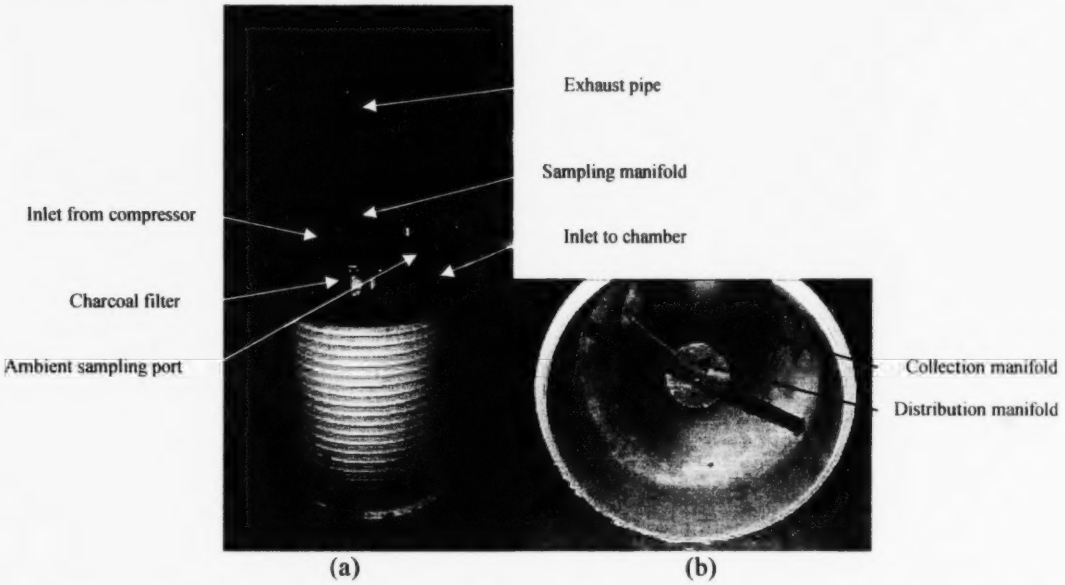

Figure 8.2.1 Circular flux chamber (a) overall outside view and (b) collection and distribution manifolds located inside the chamber.

8.2.2 Rectangular Flux Chamber

The rectangular flux chamber was designed and built by the Alberta Agricultural Research Station in Lethbridge, AB. It contains a stainless steel collar with a length and width of 0.8 and 0.4 m respectively that could be placed on the emitting soil to form a good seal. The chamber was also constructed of stainless steel with the same length and width as the collar and was sealed to the collar with a Styrofoam gasket and clamps. The chamber had a port for incoming air at one end and an exhaust tube at the other

(Figure 8.2.2). No other modifications were made at this point to assist flow through the chamber. Like the circular flux chamber, fresh air was supplied by a portable gas powered air compressor and passed through a rotameter and charcoal air filter. Samples were drawn into Tedlar bags in the same way as the circular flux chamber.

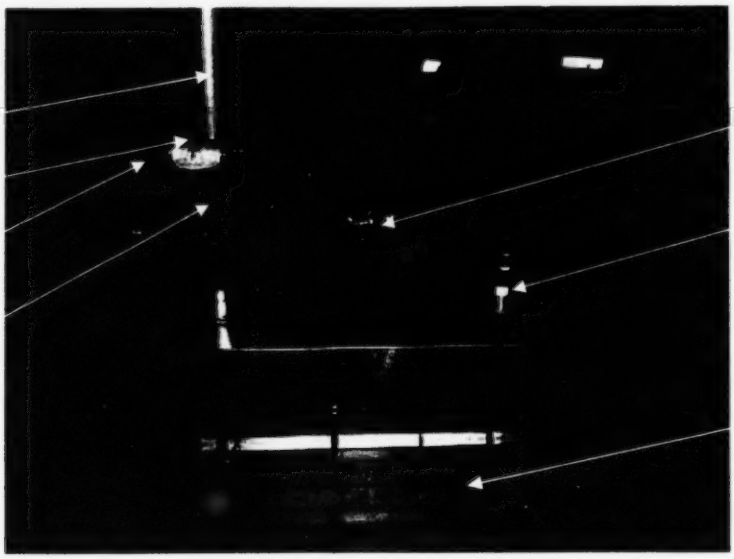

Figure 8.2.2 Rectangular flux chamber with collar.

Each chamber contains an intake from the air compressor, a charcoal filter, an ambient sampling port, an exhaust pipe and a gas sampling port. Other equipment includes a gas powered air compressor, manifold and valves and a rotameter for each chamber. All connections are made with teflon tubing (reinforced with garden hose to prevent kinking) and standard hose clamps. Samples are drawn into Tedlar bags using a vacuum chamber (not shown).

8.2.3 Chamber Operation

To collect a sample from either chamber, the chamber first needs to be placed on the emitting surface and pushed into the surface by approximately 1 cm to provide a good seal. The second step is to ensure that all connections are tight and there are no kinks in the tubing and hoses that could restrict flow. The compressor can then be started and the valve(s) and rotameter(s) to the chamber(s) from which samples are to be collected samples is or are opened. It is preferable to let air run through the chambers for about 20 minutes in order to reach steady state conditions.

For sample collection, the hose from the vacuum chamber must be connected to the gas sampling port located in the exhaust pipe of the flux chamber. Additional vacuum chambers are required when simultaneously collecting samples from more than one flux chamber. The connecting hose must be flushed by the sampled air for at least 30 seconds before the sampling Tedlar bag is allowed to fill. The emitted gas flux can then be determined as per Equation (8.2.1):

$$Flux_{chamber} = \rho_{gas}(C_{sample} - C_{ambient})\frac{Q_{chamber}}{A_{chamber}} \qquad (8.2.1)$$

Where $Flux_{chamber}$ = the gas flux collected by the chamber (mg/m^2-s)
ρ_{gas} = the density of the collected gas at ambient temperature and pressure (kg/m^3)
C_{sample} = the gas concentration of the sample collected from the flux chamber (ppm)
$C_{ambient}$ = the gas concentration of the ambient air (ppm)
$Q_{chamber}$ = the air flowrate supplied to the flux chamber (m^3/s)
$A_{chamber}$ = the cross sectional area of the flux chamber (0.323 m^2 for the rectangular chamber and 0.28 m^2 for the circular chamber)

8.2.4 Chamber Calibration

A calibration box can be used to test the capture efficiency of the chambers (Figure 8.2.3). The box includes an open top, a CO_2 gas supply, a water manometer, variable speed fans for air circulation, a CO_2 gas analyzer, a gas sampling port and a relief valve at the rear of the box. The box is filled with CO_2 that emits through the open top, simulating a soil gas flux. The chambers are operated on top of the box and the CO_2 flux collected in the chambers is compared to the actual flux by continually monitoring the CO_2 concentration in the calibration box. The chambers are operated exactly as outlined in Section 8.2.3, however, the CO_2 concentration in the calibration box and the time must be measured and recorded at the beginning and end of the sampling period.

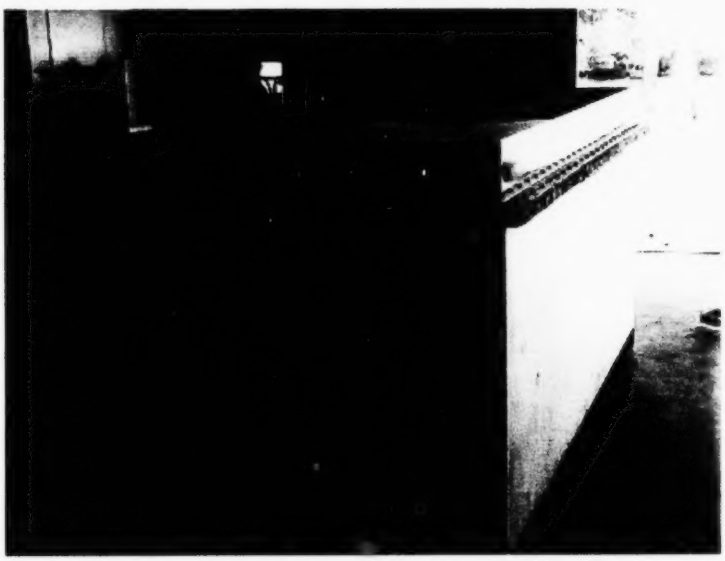

Figure 8.2.3 Overall view of calibration box (1.22 m wide, 2.44 ft wide, 1.22 m high) (4 ftx8 ft x4 ft), with an open top and no soil. Ports on front panel are (from left to right): CO_2 supply port, water manometer for monitoring pressure inside box, variable control for circulating fan speed, power bar for supply for fans, CO_2 analyzer, and collection manifold. A gas relief valve was installed at the back of the box.

To use the calibration box, make sure the soil surface is even and close the valve at the back of the box. Place the chambers on the surface and start the compressor. Connect the CO_2 gas analyzer to the calibration box sampling port on the three way valve and open the valve to the analyzer and close the valve for the vacuum box. Turn on the circulating fans to setting "3". Slowly open the CO_2 supply until you can hear the gas entering the calibration box. Watch the output on the CO_2 gas analyzer and, once it reaches about 2000 ppm, turn off the CO_2 gas supply. Ensure there is little or no pressure buildup inside

the box by looking at the water level in the water manometer. Allow the CO_2 concentration in the box to reach equilibrium (about 10 minutes) by monitoring the CO_2 concentration. Once it reaches a maximum and slowly and steadily starts declining, the calibration box is in steady state.

If the chambers are also at steady state, you are ready to start sampling. Connect the vacuum box to the chamber(s) and flush the lines. Record the time and CO_2 concentration. Fill the bag to 40% and close the valve on the bag. Wait approximately 10 minutes and fill the bag to 80% capacity and record the time and CO_2 concentration inside the calibration box. The ambient air sample can be drawn during the 10-minute wait. The bag must be filled over this longer sampling period to achieve a measureable flux from the calibration box. The CO_2 concentration in the box should drop at least 100 ppm during the sampling period to ensure the experimental error (error in CO_2 concentration, volume measurements, etc.) does not significantly impact the flux measurement. The actual flux exiting the box can be calculated using Equation (8.2.2) and compared with the CO2 flux measured by the chamber (Equation (8.2.1)).

$$Flux_{box} = \frac{V(C_{t1} - C_{t2})\rho_{CO2}}{A(t_2 - t_1)} \qquad (8.2.2)$$

Where $Flux_{box}$ = the CO_2 flux emitting from the surface (mg CO_2/m^2-s)
V = the volume of the calibration box (2.56 m^3)
C_{t1} = the concentration of the gas in the box at the beginning of the sampling period (ppm)
C_{t2} = the concentration of the gas in the box at the end of the sampling period (ppm)
ρ_{CO2} = the density of CO_2 at ambient temperature and pressure (1.8 kg/m^3)
A = the surface area of the calibration box (2.97 m^2)
$(t_2 - t_1)$ = the sampling time (s)

8.3 Detailed Results from Nasal Rangers

The odour intensity surrounding liquid injection sites are presented in Tables 8.3.1, 8.3.2 and 8.3.3 and the corresponding data for surface application sites are presented in Tables 8.3.4 and 8.3.5. In all these tables, each entry in italics corresponds to the average of ten readings and the location values in brackets indicate the distance downwind from the edge of the application site.

8.3.1 Liquid Injection Sites

At site 1 (Table 8.3.1), liquid swine manure was injected using a drag line system. The earthen manure storage had been agitated for 20 hours prior to the start of data collection and approximately 80 acres had already been applied when data collection began and continued throughout. The barn and manure storages were approximately 300 m downwind of location 1 and, therefore, did not contribute to the odour perceived in the field. In this case, location 1 was only 360 m downwind of the edge of application site and location 6 was 180 m upwind of the edge of the application site (the final protocols and maximum distance downwind had not been established at the time these data were collected). Location 5 was located 10 m upwind of a large puddle of liquid manure, possibly contributing to the higher intensity readings at that location.

Table 8.3.1 Odour intensity data for liquid injection (site 1). (Each entry in *italics* corresponds to the average of ten readings at the corresponding sampling point).

Position (° from downwind direction)	Location 1 (360 m)	Location 2 (250 m)	Location 3 (140 m)	Location 4 (30 m)	Location 5 (-80 m)	Location 6 (-180 m)
-9	*2.4*	*1.9*	*3.0*	*3.5*	*4.7*	*4.5*
-3	*0.8*	*0.5*	*1.2*	*1.5*	*3.3*	*3.0*
3	*1.0*	*1.3*	*1.6*	*2.3*	*3.9*	*3.3*
9	*1.2*	*1.5*	*2.7*	*3.7*	*4.6*	*4.5*
average	1.3	1.3	2.1	2.7	4.1	3.8
standard error (%)	54.7	45.8	40.0	37.5	16.1	20.3

Weather conditions: sunny and clear (solar radiation = slight), average wind speed = 1.4 m/s, temperature = 10.2°C, RH = 28.7% (Stability class B, moderately unstable).

The standard error of the intensity values indicates the high variability of the results. When the assessors were far from each other and from the odour source, the standard error of the intensity was high (40-55%) while the variability was much lower when the assessors were close to each other and the source and the intensity was relatively high (standard error = 16-20%). This indicates that there may be a significant difference in the odour intensity 360 m downwind among the positions (~80 m apart) or that it may be difficult to differentiate among the lower odour intensities. The higher intensities may be more distinct (and thus have a lower standard error) but the assessors were also positioned very close to each other during the high intensity readings. It is difficult to say whether the lower variability close to the source was due to the close proximity of the assessors or the high intensity of the measured odours.

Table 8.3.2 summarizes the intensity results from another liquid injection drag-line site. In this case, location 1 was 800 m downwind of the edge of the application site and location 6 was at the edge of the application site. The barn and manure storages were approximately one kilometer upwind of the application site and they may have contributed to the odour assessed in the field. Agitation of the manure storage had begun approximately 20 hours prior to data collection.

Table 8.3.2 Odour intensity data for liquid injection site 2. (Each entry in *italics* corresponds to the average of ten readings at the corresponding sampling point).

Position (° from downwind direction)	Location 1 (800 m)	Location 2 (640 m)	Location 3 (480 m)	Location 4 (320 m)	Location 5 (160 m)	Location 6 (0 m)
-12	*1.4*	*2.6*	*2.8*	*4.0*	*4.7*	*4.7*
-6	*1.8*	*2.2*	*2.8*	*4.1*	*4.5*	*4.9*
0	*1.3*	*1.7*	*2.0*	*3.1*	*3.6*	*4.7*
6	*1.4*	*1.6*	*2.4*	*3.5*	*4.5*	*5.0*
12	*2.0*	*2.3*	*2.8*	*3.8*	*4.4*	*5.0*
average	1.5	2.0	2.5	3.7	4.3	4.8
standard error (%)	15.0	22.9	15.3	12.6	11.4	3.1

Weather conditions: clear and calm (solar radiation = moderate), average wind speed 1.2 m/s (gusting to 4.3 m/s), temperature 25°C, relative humidity 34%. (Stability class A-B, very to moderately unstable).

In this case, even the lower intensities far from the source had a lower variability (standard error 15%) and the intensity increased predictably closer to the application site. However, the results from site 1 do not compare well with those from site 2. Even though liquid swine manure had been applied in the same manner and at approximately the same application rate at both sites under similar weather conditions, the average intensity 360 m downwind of site 1 was 1.3 whereas the average intensity 320 m downwind of

site 2 was 3.7. The fact that the manure at site 2 had been stored in a concrete storage tank rather than an earthen manure storage basin may have contributed to the higher intensity of odours within 360 m of the application site.

Table 8.3.3 summarizes the odour intensity downwind of a liquid manure injection site using the modified field protocol outlined in Section 3.3.1. Ranger 3 was positioned near the center of the application area in the downwind direction. The rangers were separated by 30 m at all locations. Again, liquid manure was injected using a drag-line system at a similar application rate (9,000 gal/acre or 84.3 m^3/ha). Agitation of the earthen manure storage had begun 24 hours prior to Nasal Ranging and the barn and manure storage were approximately one kilometer upwind of location 1. Approximately 50 acres had been applied prior to the start of Nasal Ranging and application continued uninterrupted throughout the sampling period. A large slough in the downwind direction limited the maximum achievable distance. However, readings from a road approximately 750 m downwind of the application site were an intensity 0 and the intensity at location 1 (300 m downwind) was also very low.

Table 8.3.3 Odour intensity data for liquid injection (site 5). (Each entry in *italics* corresponds to the average of ten readings at the corresponding sampling point).

	Location 1 (300 m)	Location 2 (240 m)	Location 3 (180 m)	Location 4 (120 m)	Location 5 (60 m)	Location 6 (0 m)
Ranger 1	*0.2*	*0.5*	*0.1*	*1.7*	*1.5*	*4.1*
Ranger 2	*0.0*	*n/a*	*0.4*	*2.4*	*2.8*	*4.6*
Ranger 3	*0.0*	*0.9*	*0.0*	*1.6*	*1.4*	*3.6*
Ranger 4	*0.0*	*1.3*	*0.1*	*1.7*	*1.7*	*3.3*
average	0.05	0.90	0.15	1.85	1.85	3.90
standard error (%)	200.0	44.4	115.5	20.0	34.9	14.7
offensiveness	5.0	3.7	5.0	3.5	3.5	2.3

Weather conditions: overcast (solar radiation = slight), average wind speed = 1.6 m/s, temperature = 0°C, RH = 43% (Stability class D, neutral).

These results compare reasonably well with the results from site 1. The intensity was very low more than 200 m from the application site and the intensity at the edge of the application site was 3.9 (3.8 to 4.1 at site 1). These results also indicate that, close to the source, the odour plume is relatively stable. Even though the assessors were 30 m apart at the edge of the application site, the standard error of the readings was very low (14.7%). This may also indicate that higher odour intensities are more distinct. Predictably, the offensiveness ratings decrease (become more unpleasant) as the intensity increases.

8.3.2 Liquid Surface Application Sites

Because of the presence of a short-term manure storage facility at sites 3 and 4, the liquid splash-plate applications occurred on areas approximately 8 hectares in size. In both cases, manure application finished as the assessors were collecting data at location 4. At site 3, the assessors' positions were not corrected after an early wind shift so the data collected represent only one side of the odour plume. The assessor on the far right was at approximately the centre of the plume. In addition, an elevated (~1.5 m) road served as a barrier between the application site and the assessors. The barn and manure storages were approximately one kilometer upwind of the edge of the application site and may have contributed to the odour observed in the field.

Table 8.3.4 Odour intensity data for liquid surface application site 3. (Each entry in *italics* corresponds to the average of ten readings at the corresponding sampling point).

Position (° from downwind direction)	Location 1 (600 m)	Location 2 (480 m)	Location 3 (360 m)	Location 4 (240 m)	Location 5 (120 m)	Location 6 (0 m)
-30	*1.0*	*1.0*	*1.0*	*1.1*	*1.1*	*2.0*
-24	*1.0*	*1.0*	*1.0*	*1.4*	*2.2*	*1.9*
-18	*1.0*	*1.1*	*1.6*	*2.5*	*2.4*	*2.2*
-12	*1.9*	*1.2*	*2.3*	*3.5*	*3.7*	*3.3*
-6	*2.8*	*1.4*	*1.7*	*3.0*	*2.6*	*1.4*
0	*3.0*	*2.8*	*2.6*	*3.2*	*3.8*	*2.7*
average	1.2	1.1	1.5	2.1	2.4	2.4
standard error (%)	36.7	8.9	41.9	51.6	45.4	27.5

Weather conditions: partly to mostly cloudy (solar radiation = slight), temperature 22°C, 39% RH, wind speed average 3 m/s, gusting to 6 m/s. (Stability class C, slightly unstable).

Table 8.3.5 Odour intensity and offensiveness data for liquid surface application site 4. (Each entry in *italics* corresponds to the average of ten readings at the corresponding sampling point).The offensiveness values are the average of the 5 assessors at each location.

Position (° from downwind direction)	Location 1 (460 m)	Location 2 (370 m)	Location 3 (280 m)	Location 4 (190 m)	Location 5 (100 m)	Location 6 (0 m)
-12	*0.5*	*0.9*	*0.7*	*0.7*	*3.0*	*3.9*
-6	*1.8*	*1.7*	*1.1*	*0.2*	*1.1*	*3.0*
0	*1.6*	*1.6*	*2.0*	*1.5*	*1.2*	*3.7*
6	*0.1*	*0.8*	*1.3*	*0.5*	*2.2*	*4.9*
12	*0.1*	*0.2*	*0*	*0.4*	*1.3*	*4.5*
average	1.0	0.5	1.3	0.7	1.5	4.0
standard error (%)	82.9	37.2	42.7	76.7	34.9	21.0
offensiveness	4.6	4.2	4.4	4.8	4.6	2.4

Weather conditions: partly cloudy (solar radiation = moderate), wind speed = 1 - 2 m/s, temperature = 20°C, 70% RH (Stability class A-B, very to moderately unstable).

At site 4, the maximum distance downwind of the application site was limited due to physical barriers (trees, mature canola crop). The barn and manure storages were downwind of the assessors at all times and did not contribute to the odour perceived in the field. A significant shift in the wind direction between locations 3 and 4 was corrected by a shift in the assessor's positions. The odour offensiveness was also recorded at this particular site.

The results from sites 3 and 4 compare reasonably well with each other in that the odour intensity at distances greater than 100 m from the application site was low (less than 2.4 at site 3 and less than 1.5 at site 4). However, site 4 recorded a sharp increase in intensity at the edge of the application site that was not observed at site 3. The elevated barrier at site 3 may have contributed to the low intensity recorded at the edge of the application site. The offensiveness ratings at site 4 appear to be correlated with the intensity values. Low odour intensity values correspond with the neutral or dislike slightly offensiveness ratings. The intensity 4 readings had an offensiveness of 2.4 (dislike very much to dislike moderately).

8.3.3 Solid Broadcast Application Sites

For the first solid manure broadcast application site (Fall, 2006), the application was sporadic and in unfavourable weather conditions for Nasal Ranging (wind speed too high, temperature too low). One assessor collected intensity and dilution to threshold data approximately 600 m downwind of the application site over the course of 2 two hour sessions. Measurements were made during and immediately after spreading (2-minute intervals) and during the transport and loading interval (45 minutes to an hour). Measurements were also made at the same site 24 hours after application had stopped. For the majority of the readings, the wind was from the south at 6.1 m/s, the sky was partly cloudy, temperature was 2°C and the relative humidity was 70%. Assuming the solar radiation was slight (mid-afternoon in the fall), this corresponds to a weather stability class D (neutral).

The intensity was 2 to 3 between all applications and immediately after some applications. For some cases, the intensity increased to 5 immediately after application and the offensiveness was 1 (dislike extremely). These intense, offensive bursts lasted from one to two minutes. Immediately after one of these bursts, the assessor moved to the nearest downwind neighbour (~1.5 km downwind) but the intensity was 0 at that location. In general, the odour intensity was 2 to 3 at 600 m downwind throughout the application period (approximately 3 hours on the sampling day). However, the barn and manure storages were upwind of the sampling location and may have contributed to some odour. One day (24 hrs) after application stopped, the intensity was 1 at the same location (wind direction was same).

At the next 2 solid broadcast sites (Summer, 2007), 2 trained assessors collected odour intensity measurements up to 650 m downwind of the application site. Since only 2 sets of data are available for these sites, calculation and discussion of standard errors is not relevant. The measurement sessions occurred on consecutive days with similar atmospheric conditions and the same manure, applicator and application rate (solid swine manure, approximately 50 Mg/ha). On average, the odour intensity at the maximum distance was 1.1 but a few observations of intensity 3 were noted. The intensity increased steadily as the distance between the assessors and the application site decreased, with the maximum intensity of 5 being observed at the edge of the application site.

9. ADMINISTRATIVE / OTHER ASPECTS

9.1 Research Team

Principal Investigator: Claude Laguë, P.Eng., Ph.D., Dean and Professor (February 1, 2005 to August 20, 2006); Adjunct Professor (since August 21, 2006)

Collaborators (faculty): Terry A. Fonstad, P.Eng., Ph.D., Assistant Professor
Huiqing Guo, P.Eng., Ph.D., Assistant Professor

Collaborators (professionals): Joy Agnew, E.I.T., M.Sc., Research Engineer (February 1 – August 31, 2005)
Subrata Karmakar, Ph.D., Research Associate (September 1 – October 31, 2005); Post-Doctoral Fellow (November 1, 2005 to January 31, 2007).

Collaborators (students): Joy Agnew, P.Eng, M.Sc., Ph.D. student (since September 1, 2005)
Wadena Burnett, Undergraduate Research Assistant (Summer 2005)
Pamela Loran, Undergraduate Research Assistant (Summers 2005, 2006, and 2007)
Peter Rhodes, Undergraduate Research Assistant (Summer 2005)
Chris Reid, Undergraduate Research Assistant (Summer 2006)

Collaborators (technicians): Randy Lorenz

9.2 Research equipment and materials

- Vented flux chamber from Lethbridge
- Equipment and supplies for modifications to existing dynamic chamber and vacuum box
- Equipment and supplies for calibration equipment
- GC analysis of calibration gases
- Tedlar bags for gas collection
- N-butanol for reference odour kits
- Nasal Ranger equipment (2-way radios, respirators, etc.)
- Portable, wireless weather station
- Payment of Nasal Rangers
- Truck rental/fuel for field days
- GC analysis for GHG emission data
- Olfactometer analysis for odour emission data
- Analysis of manure composition
- Thick-walled Teflon tubing for flux boxes and vacuum box
- Odour sensitivity kit
- Replacement filter cartridges for Scentometer

9.3 Communication of research results

Agnew, J., P. Loran, S. Karmakar, C. Laguë. 2006. Greenhouse gas and odour emissions from land application of manure: a review of measurement methods. Paper presented at the ASABE/CSBE Annual Intersectional Meeting, Saskatoon, SK, October 5-7, Paper MBSK 06-305.

Agnew, J., P. Loran, S. Karmakar, C. Reid, C. Laguë. 2006. Use of trained odour assessors to monitor odour intensity, duration and offensiveness downwind of manure applications sites. Paper presented at the ASABE/CSBE Annual Intersectional Meeting, Saskatoon, SK, October 5-7, Paper MBSK 06-307.

Karmakar, S., M. Nketia, C. Laguë, J. Agnew and H. Landry. 2006. Expert System Modeling of Liquid Manure Management for Integrated Decision Support System of Swine Manure Management. Paper presented at the ASABE/CSBE Annual Intersectional Meeting, Saskatoon, SK, October 5-7, Paper MBSK 06-107.

Loran, P., J. Agnew, P. Rhodes, W. Burnett, and C. Laguë. 2005. Performance and calibration of two types of vented chambers for agricultural emission collection. ASABE Paper SD05-500. Conference presented at the North Central ASABE/CSBE Conference 2005 hosted by the South Dakota – Great Plains Section of ASABE. St. Joseph, MI, USA.

Respectfully submitted,

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August 15, 2007